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Power supply device comprising several switched-mode power supply units that are connected in parallel

The invention relates to a power supply device having several switch-mode power supplies connected in parallel to supply at least one load, each switch-mode power supply generating an output current and an output voltage, and having a control device for each switch-mode power supply. The control device controls the output voltage of the switch-mode power supply which is a dependent on the output current and a load resistance.

The basic principles of switch-mode power supplies connected in parallel are described, for example, in Elektronik, Volume 13, 2000, pages 114-118 "Schaltnetzteile parallel geschaltet – technische Details zur passiven Stromaufteilung" by Martin Rosenbaum. The aim of connecting switch-mode power supplies in parallel is to increase the power by increasing the output current and to reduce the failure rate by providing redundant switch-mode power supplies in such a way that a defective power supply unit can be exchanged during the operation of a device which is supplied by the switch-mode power supplies. Connection in parallel can be realized by means of an active current division or a passive current division.

Active current division measures the output current of each power supply and controls the output voltages as a function of the output current of all switch-mode power supplies resulting in a uniform division of current to one or more loads. This method has the advantage that an exact division of current and a uniform load on the switch-mode power supplies connected in parallel can be achieved. The disadvantages can be seen in the greater complexity of the circuitry and the higher costs thus incurred.

In the case of passive current division, the current division is made as uniform as possible by setting a "softer output characteristic" for the switch-mode power supply as shown, for example, in figure 1. The advantages include a less complex circuitry and the almost limitless number of switch-mode power supplies that can be connected in parallel. A disadvantage is the somewhat less exact division of current in some applications.

Figure 2 shows a block diagram of an example for N switch-mode power supplies 10, 11, 12 connected in parallel which supply a load 13. Further details on the circuit illustrated in figure

2 are illustrated and explained in the above-mentioned article in Elektronik 13/2000. Reference is made to this publication.

In order to set the output characteristics of the individual switch-mode power supplies connected in parallel as required, where passive current division is concerned the prior art provides for one or more shunt resistors to be added to the output line of the respective switch-mode power supplies so that the output voltage of the respective switch-mode power supplies is established as a function of the load, within certain tolerances, according to predetermined characteristics. Figure 3 shows an example of such an output characteristic for a single switch-mode power supply which has three ranges that can be established by the provision of three shunt resistors connected in the output line of the switch-mode power supply.

The output characteristic shown in figure 3 occurs in a first range I, which characterizes the normal operation of the switch-mode power supply, being relatively flat with only a slight voltage drop following an increase in output load and thus an increase in output current. A first shunt resistor $R_{VS}$ is active in this range I, which could also be formed by the line resistance. When the output current $I_0$ exceeds a first threshold value $I_{0P}$, a second shunt resistor $R_P$ is connected which causes the voltage at the output of the switch-mode power supply to fall more strongly. This second range, indicated by II, can, for example, be a charging range in which the power supplies not only supply a load but also charge batteries or other energy storage units, which are intended as an emergency power supply to supply the load during a power failure.

When the output current $I_0$ of the respective switch-mode power supply exceeds a further threshold value $I_{0S}$, a third shunt resistor is activated which is dimensioned in such a way that the voltage output characteristic of the switch-mode power supply declines abruptly. This range, indicated by III, can be considered a safety cut-off range in which the switch-mode power supply is short circuited and turned off when a specific threshold current $I_{0S}$ is exceeded. The third shunt resistor is indicated by $R_S$.

Although the above-described prior art solution for establishing the output characteristic of the switch-mode power supplies as a function of the output current has a simple circuitry and allows for different operating ranges of the output characteristic, the shunt resistors, which can be located in the power supply unit or outside it in the output line of the switch-mode

power supply (s.$R_L$ in fig. 2), generate considerable losses and thus reduce the overall efficiency of the power supply and of the system.

The object of the invention is to provide a power supply device having several switch-mode power supplies connected in parallel to supply at least one load which operates with a passive current division and allows the output characteristic of each switch-mode power supply to be adjusted for different operating ranges. This object is solved by a power supply device having the characteristics outlined in claim 1.

The invention proposes a power supply device having several switch-mode power supplies connected in parallel to supply at least one load in which each switch-mode power supply generates an output current $I_0$ and an output voltage $U_0(I_0, R_L)$, which is a function of the output current $I_0$ and an associated load resistance $R_L$. A control device is provided for each switch-mode power supply. In accordance with the invention, the control device is divided into three stages for the purpose of creating an output voltage characteristic of the respective switch-mode power supply having three operating ranges. These three operating ranges are preferably characterized by an output characteristic of the switch-mode power supply which declines more steeply as the load, and thus the output current, increases, as shown for example in figure 3.

The first stage has a P (proportional) element that receives a P element input voltage which is derived from the output voltage $U_0(I_0, R_L)$, and generates a P element control voltage $U_{VS}$ that is used to control the respective switch-mode power supply. The P element generates a slightly declining output characteristic whose height can preferably be adjusted. The first stage is active in a normal operating range up to a first threshold value $I_{0P}$ of the output current $I_0$ and can be deactivated on exceeding the threshold value $I_{0P}$.

The second stage has a current imaging circuit which reproduces the output current $I_0$ of the respective switch-mode power supply and generates an output current control voltage $U_P$ which is used to control the respective switch-mode power supply. The output current control voltage $U_P$ is directly proportional to the output current $I_0$ and is adjusted in such a way that a more strongly declining output characteristic of the switch-mode power supply is produced. The second stage is active when the output current $I_0$ exceeds the first threshold value $I_{0P}$ which is selected in such a way that it characterizes, for example, a departure from the normal

operation and a transition to a charging operation of the switch-mode power supply, as described above with reference to figure 3.

The third stage has an amplifier circuit which amplifies a signal proportional to the output current $I_0$ and generates an amplified output current control voltage $U_S$ which is used to control the respective switch-mode power supply. The third stage is preferably connected downstream from the second stage and uses the output current control voltage $U_P$ as its input signal. The amplification of the third stage is preferably adjusted in such a way that a steeply declining output characteristic of the switch-mode power supply is produced. The third stage is active when the output current $I_0$ exceeds a second threshold value $I_{0S}$ which, for example, indicates an overload condition making it necessary to turn off the switch-mode power supply.

The power supply device according to the invention makes it possible to adjust the output characteristic of a switch-mode power supply according to specifications in several different operating ranges, the adjustment being largely loss-free due to the use of the P element, the current imaging circuit and the amplifier circuit, but nevertheless requiring a less complex circuitry than is the case with an active current division which is based on measuring the output currents of all the switch-mode power supplies and effecting control depending on the measurement of all the switch-mode power supplies.

According to the invention, the operating ranges in which the first, second or third stage are active are controlled as a function of the output current $I_0$. The ranges are indicated in fig. 3 by I, II, III. If $I_0$ is located in range I, only the first stage is active; if $I_0$ is located in range II, the second stage is active, the P element of the first stage draws the output voltage of this first stage to zero, as described in more detail below, so that the first stage no longer exerts any influence. If the output current $I_0$ is located in range III, although the second stage remains active, the third stage dominates due to the considerably higher amplification factor so that the contribution of the second stage to the control voltage can be largely disregarded, as is explained below in more detail.

The control device preferably comprises a pulse width modulator component with an integrated coupling amplifier which receives the P element control voltage $U_{VS}$, the output current control voltage $U_P$ and the amplified output current control voltage $mU_S$ and generates a con-

trol signal $V_T$ for the respective switch-mode power supply as a function of these control voltages. Depending on which stage is activated, the pulse width modulator component receives the P element control voltage $U_{VS}$, the output current control voltage $U_P$ and/or the amplified output current control voltage $mU_S$.

In a preferred embodiment, the first stage includes a voltage divider that determines the size of the output voltage $U_0$ and generates a P element input voltage that is proportional to the output voltage $U_0$. In addition, the output characteristic of the switch-mode power supply can be shifted using a controlled current source that is connected to the voltage divider, as described in more detail below.

The P element of the first stage preferably has an operational amplifier, one of whose inputs receives the P element input voltage and whose other input receives a first reference voltage $U_{ref1}$ and whose output emits the P element control voltage $U_{VS}$. The operational amplifier is preferably connected to the pulse width modulation component via a blocking diode.

The current imaging circuit of the second stage preferably has a transformer element that is connected in parallel to the main transformer element of the respective switch-mode power supply and generates an output signal that is proportional to the output current $I_0$ of the switch-mode power supply. This is explained in more detail with reference to the figures.

The amplifier circuit of the third stage preferably takes the form of an operational amplifier, one of whose inputs being connected to the current imaging circuit of the second stage and whose other input is connected to the reference voltage and whose output emits the amplified output current control voltage.

From DE 100 19 329, a power supply having several switch-mode power supplies connected in parallel is known which is regulated to generate an output characteristic in several sections. A first segment of the characteristic has a constant output voltage, a second segment corresponds to a straight line with a declining gradient and a third segment provides a short-circuit current limiter. In the first stage, DE 100 19 329 uses an I (integrating) element to generate a constant output voltage to regulate the current – in contrast to operating range I according to the invention. The prior art circuit, however, would not function with a pure P (proportional) element. One reason is that in DE 100 19 329 the current is mainly measured by using an op-

tocoupler. The optocoupler amplification or attenuation influences the open-loop gain which determines the gradient of the characteristic. The optocoupler amplification, however, is not linear and is heavily dependent on the temperature, it is also dependent on the respective tolerances of the actual components used. Thus the solution revealed in DE 100 19 329 is not suitable for the generation of identical, reproducible characteristics for several switch-mode power supplies connected in parallel since by using different optocouplers, each switch-mode power supply would generate a deviating, non-predictable characteristic making a defined current division impossible. Moreover, the optocoupler generates non-linearities which have to be compensated by correspondingly high amplification.

An advantage of using a P element according to the invention is that current-dependent characteristics can be generated, in contrast to segment 1 of DE 100 19 329, and that the equations of the straight lines can be set more easily. This is important for the load division when several power supplies are operated in parallel.

Another very important difference between the invention and DE 100 19 329 is that DE 100 19 329, like the prior art described above, operates with a resistance shunt in the output branch. The output characteristic is mainly established by the resistance shunt and the entire output current passes through this shunt. As a result, considerable losses are incurred. Moreover, the characteristic can be less flexibly adjusted than in the invention.

In contrast, the invention does not need an ohmic load to establish the characteristic in the output branch, it being possible to set any required curve equations. The invention can nevertheless realize short circuit current limitation.

The invention is described in more detail below on the basis of preferred embodiments with reference to the drawings. The figures show:

Figure 1 a diagram with three output characteristics of three switch-mode power supplies connected in parallel according to the prior art;

Figure 2 shows in block diagram form the connection in parallel of several switch-mode power supplies to supply a load according to the prior art;

Figure 3 shows the diagram of an output characteristic of a switch-mode power supply which is to be established according to the invention;

Figure 4 shows a circuit diagram of a power supply device having a control device according to the invention, with only the output stage of a switch-mode power supply being schematically represented in figure 4;

Figure 5 shows a circuit diagram of the input stage of a switch-mode power supply according to the prior art which could be used in conjunction with the invention;

Figure 6 shows a schematic block diagram of a power supply device according to the invention for the supply of several loads.

Figure 1, which has been described above, shows a diagram with three so-called "soft" characteristics of three switch-mode power supplies connected in parallel with a passive current division according to the prior art. An example of three or n switch-mode power supplies connected in parallel according to the prior art is shown in figure 2. Figure 2 shows a first switch-mode power supply 10, a second switch-mode power supply 11, and an nth switch-mode power supply 12, which are connected in parallel and wired symmetrically to a load 13. The line resistances of the wiring are schematically represented by the resistors $R_L$. In the arrangement shown in figure 2, the line resistors $R_L$ correspond to the first shunt resistor to set the output characteristic of each switch-mode power supply 10, 11, 12, it being necessary in the prior art to provide an additional shunt resistor in order to achieve an exact current division. This solution is inflexible, however, and results in additional losses at the shunt resistor.

Figure 3, which has been described above, shows an output characteristic of a switch-mode power supply having three operating ranges which are to be created by the power generating device according to the invention. Applied to the schematic representation in figure 2, it is the object of the invention that each of the switch-mode power supplies 10, 11, 12 generates an adjustable output characteristic, such as an output characteristic in accordance with figure 3 or any other, without the need for loss-related shunt resistors. Figure 3 shows a first operating range I which characterizes the normal operation of the power supply device and ends at a first threshold current $I_{0P}$, a second operating range II, which characterizes the charging operation of the power supply device according to the invention and ends at a second threshold current $I_{0S}$, and a third operating range III, which characterizes the cut-off range of the power supply device according to the invention, the power supply device cutting out completely when there is a short-circuit current $I_K$.

Figure 4 shows a schematic circuit diagram of the power supply device according to the invention with only the output stage of a switch-mode power supply and the associated control device being schematically illustrated in figure 4.

Figure 4 schematically illustrates the output stage of a switch-mode power supply 20 having a controlled electronic switch 22, which is a MOS-FET in the illustrated embodiment but can be realized as an IGBT or any other suitable transistor switch, and a storage capacitor 24 as well as an output transformer 26. Downstream from the output transformer 26 are an output/free-wheeling diode 28 and an LC circuit 30 which rectify the chopped output voltage of the transistor switch 22 and transformer 26. The output current of the switch-mode power supply 20, that is illustrated only schematically in figure 4, is indicated by $I_0$, and the output voltage is indicated by $U_0$. At the output of the switch-mode power supply 20, a load resistor $R_L$ 32 is illustrated in figure 4 representing one or more loads. In the embodiment illustrated in fig. 4, the output stage of the switch-mode power supply 20 further comprises a second controlled electronic switch 61 which is controlled in common mode with the first switch 22.

For explanatory purposes, figure 5 shows an example of an input stage of the switch-mode power supply according to the prior art which can be connected upstream of the output stage shown in fig. 4. However, this input stage of a switch-mode power supply serves only by way of example since the invention can be realized using all kinds of switch-mode power supplies. In particular, the switch-mode power supply of figure 5 comprises an input rectifier consisting of four rectifier diodes 34, 35, 36, 37, which are arranged in the form of a bridge circuit. The rectifier bridge receives its input AC voltage, in particular a mains voltage, at the connections X1, X2 and sends its rectified output voltage via a storage and smoothing inductor 38, through which a current passes in one direction only, to a controlled electronic switch 40 which is connected via the output of the bridge rectifier. The transistor switch 40 receives a control voltage $U_i$, which is not specified in more detail in fig. 5 and determines the output voltage of the switch-mode power supply. Associated with the transistor switch 40 is an output/free-wheeling diode 42 which rectifies the chopped output voltage of the transistor switch. At the output of the switch-mode power supply, a unipolar storage capacitor 44 is connected to store and smooth the output voltage.

According to a well-known control method, the controlled electronic switch 40, or 22, 61 in figure 4, is operated at a high switching frequency $U_T$ compared to the mains frequency of

the AC voltage supply (at the connections X1, X2). By changing the relative switch-on duration of the electronic switch 40 or 22, 61, it is possible to adjust the output voltage $U_C$ at the capacitor 44 or 24 and thus the output voltage of the switch-mode power supply $U_0$.

Referring again to figure 4, we will now describe how the control voltage $U_T$ is determined by means of the three-stage control device according to the invention. The first stage of the control circuit according to the invention is illustrated in figure 4 in a box indicated by 50, the second stage is in a box indicated by 60 and the third stage is in a box indicated by 70.

The first stage 50 of the control circuit comprises a voltage divider consisting of resistors 51, 52, 53, a P element, that takes the form of an operational amplifier 54, and a blocking diode 56. These components are connected to each other as shown in figure 4. The output voltage $U_{0MAX}$ can be adjusted via the voltage divider 51, 52, 53 and a selectable, constant first reference voltage $U_{REF1}$.

The voltage divider 51, 52, 53 is dimensioned in such a way that for the required output voltage $U_0$, a voltage is generated at the connection between the resistors 52 and 53, this voltage essentially corresponding to the first reference voltage $U_{REF1}$. Accordingly, the P element 54 generates a P element control voltage $U_{VS}$, which is applied via the diode 56 to a pulse width modulation component 80 in order to control the switch-mode power supply 20 in such a way that produces the slightly declining output characteristic (due to the effect of the P element) in range I of fig. 3.

In a preferred embodiment of the invention as shown in fig. 4, a current reduction device 58 can be provided to adjust $U_{0MAX}$ in order to generate a characteristic field according to requirements. A second characteristic with a slightly downwards shifted $U_{0MAX}$ is shown in fig. 3, for example, by the broken line. For this purpose, the voltage divider is divided into the resistors 51 ($R_T$) and 52 and a controlled current source or a current reduction device 58 is connected to the connecting point between the resistors 51 and 52. The current reduction device 58 draws a constant current $I_T$ through the resistor 51 ($R_T$), so that at the resistor 51, an additional constant, adjustable voltage drop occurs which shifts the output characteristic of the switch-mode power supply as required.

The output signal $U_{VS}$ of the P element 54 is applied to the pulse width modulation component 80, having an integrated coupler amplifier, which generates the control signal $U_T$ for the switch-mode power supply 20.

As long as the output current $I_0$ of the switch-mode power supply 20 remains under a predetermined first threshold value $I_{0P}$ that characterizes the end of a normal operating range I, the second stage 60 and the third stage 70 do not emit any output signals. The output voltage of the switch-mode power supply 20 is then given as:

$$U_0 (I_0) = U_{0MAX} - R_{VS} * I_0 - R_T * I_T,$$

where

$$R_{VS} = \frac{R_{Leistungsverluste}}{Kreisverstärkung}$$

When the output current $I_0$ exceeds the first threshold value $I_{0P}$, the second stage 60 is activated in the illustrated embodiment. The second stage 60 is active in range II, the output voltage $U_0$ in this range being smaller than the first reference voltage $U_{REF1}$, so that the P element 54 of the first stage has a high-ohmic output and the first stage 50 thus makes no further contribution to the adjustment of the control signal $U_T$.

The second stage 60 of the control device consists of a transformer 62, a zener diode 63, a capacitor 64 and a resistor $R_P$ 65, which are connected to each other as shown in figure 4. The transformer 62 is controlled by the electronic switch 61.

The control signal $U_T$ is applied in parallel to the two electronic switches 22, 61 so that they are switched in common mode. The primary current of the switch-mode power supply, which flows through the switches 22, 61 and the transformer 62, corresponds exactly with the secondary current through the diodes 28, multiplied by $ü_1$. The transformer 62 divides the primary current by $ü_2$. Thus the output current through the second transformer 62 is an exact replica of the output current $I_0$ of the main transformer 26 divided by ($ü_1 \cdot ü_2$). The voltage

drop via the resistor $R_P$ 65 is thus a measure for the output current $I_P$, according to the following equation:

$$U_P = \frac{I_0 \cdot R_P}{\ddot{U}_1 \cdot \ddot{U}_2}$$

Thus with the aid of the second transformer 62, a replica of the output current $I_0$ can be generated without any significant current load on the switch-mode power supply. The output voltage $U_P$ of the second stage 60 is applied to the pulse width modulation component 80 via a controlled switch 68. At a control input, the controlled switch 68, schematically illustrated in fig. 4 by a comparator and a transistor switch, receives a second reference voltage $U_{REF2}$ which is selected in such a way that the output signal $U_P$ of the second stage is only imposed on the pulse width modulation component 80 when the output current $I_0$ exceeds the second threshold value $I_{0P}$. For this purpose, $U_{REF2}$ is adjusted as follows:

$$U_{REF2} = \frac{I_{0P} \cdot R_P}{\ddot{U}_1 \cdot \ddot{U}_2}$$

the output voltage $U_P$ of the second stage 60 is applied to the pulse width modulation component 80 as described above in order to control the pulse width modulation component 80 and to generate a required control signal $U_T$ for the switch-mode power supply.

On activation of the second stage 60, the output voltage $U_0$ of the switch-mode power supply 20 is given as:

$$U_0(I_0) = U_0(I_{0P}) - k * R_P * I_0$$

where

$$k = \frac{1}{\ddot{U}_1 \cdot \ddot{U}_2}$$

It is clear that through a suitable choice of $R_P$, the rise in the output characteristic of the switch-mode power supply 22 can be influenced. Since the characteristic is only adjusted with the aid of the current imaging, it is not necessary to add another resistor to the actual output circuit of the switch-mode power supply so that losses can be kept to a minimum.

When the output current $I_0$ then exceeds a second threshold value $I_{0S}$, the third stage 70 of the control circuit is activated. The activation of the third stage 70 can be adjusted via a third reference voltage $U_{REF3}$, where

$$U_{REF3} = \frac{I_{0S} \cdot R_P}{\ddot{U}_1 \cdot \ddot{U}_2}$$

The third stage 70 of the control circuit consists of an input diode 71 and a capacitor 72, which form an input rectifier, as well as an amplification circuit, which is indicated in its entirety by 74 and, alongside other resistors and capacitors, has an input resistor $R_S$ 73, and an output diode 75, which are connected to each other as shown in fig. 4. The third stage 70 of the control device receives as its input signal the output signal $U_P$ of the second stage 60 which is proportional to the output current $I_0$ of the switch-mode power supply 20. $U_P$ is a pulsed signal dependent on the control signals $U_T$. This pulsed signal $U_P$ is rectified by the rectifier part 71, 72 of the third stage 70 so that a rectified voltage $U_S$ is applied at the input resistor $R_S$ 73 of the amplifier part 74 of the third stage, the amplitude of the rectified voltage corresponding to the voltage $U_P$. The third stage 70 generates a control signal $U_S = U_P$ (rectified) $= k \cdot R_P \cdot I_0$, that is amplified by the amplifier circuit 74. The amplifier circuit 74 is designed in such a way that it has a relatively high amplification factor, $m >> 1$. An output signal $m \cdot U_S$ is produced.

The output signal $mU_S$ of the third stage 70 is entered into the pulse width modulation component 80 in order to generate the control signal $U_T$ that generates a steep output characteristic $U_0$ of the switch-mode power supply 20 which, for a short-circuit current $I_K$, becomes 0 (see range III in fig. 3). The output characteristic $U_0$ of the switch-mode power supply 20 is in the range $I_{0S} < I_0 < I_K$:

$$U_0(I_0) = U_0(I_{0S}) - k * m * R_P * I_0$$

The power supply device according to the invention is used in all systems in which redundant switch-mode power supplies are needed for purposes of safety during a power failure or suchlike. The invention can particularly be employed in telecommunications systems, computer systems and all other kinds of control and communications systems which need a failure-proof energy supply. In addition to the loads connected to the power supplies, batteries can also be connected which take over the supply of energy during a power failure. In its output characteristic, the power supply device according to the invention thus provides an operating range for normal operation, an operating range for charging operation under higher load and an operating range for a cut-off when there is an overload.

Figure 6 shows an example of an environment in which the power supply device according to the invention can be employed. In figure 6, a mains supply is indicated in general by 90, the mains supply 90 providing an AC voltage in the range of 90 to 230 volts and having a device for the distribution of the AC voltage to several switch-mode power supplies and the necessary interference filters on the mains side and other necessary filter devices. The mains 90 supply n switch-mode power supplies 92, 94, 96, 98 that are indicated in figure 6 by Rectifier Module. In the illustrated embodiment, the switch-mode power supplies 92-98 should be able to provide an output power POUT of between 300 W and 2 kW. A control device, as described in reference to figure 4, is associated with each switch-mode power supply of figure 6 in order to establish a desired output characteristic, the control devices not being illustrated in figure 6. The switch-mode power supplies 92-98 are connected via a common line to several loads 100-112 as well as to batteries 114, all of which operate with a voltage in the range of 48 volts DC to 56 volts DC and which can have different power requirements, power ranges POUT from 10 watt to 100 watt and from 100 W to 300 kW being given by way of example. The loads 100-112 can include micro processor cards, telecommunications cards, DC converters on cards in electronic data processing systems, 19 inch DC converters for server cabinets or suchlike, all kinds of electric and electronic systems, ventilators and air conditioning units and suchlike. One example of the invention's application is in telecommunications systems which have all these components. In normal operation, i.e. in range I of the characteristic shown in figure 3, the power supplies 92-98 supply the loads 100-112 with an essentially uniform current flow and maintain the voltage of the batteries 114 at a required level, e. g. 48-56 V. When the voltage level of the batteries 114 falls during start-up or due to a disruption, during maintenance or such like, the switch-mode power supplies 92-98 have to recharge the

batteries 114 in addition to supplying the loads 100-112 so that the output current of the switch-mode power supplies 92-98 increases due to the heavier load which means that the output characteristic of the switch-mode power supplies moves into operating range II. Once the batteries 114 have been fully charged, the current drain generally decreases again so that normal operation in operating range I can once more be assumed. In the event of a malfunction or failure in which an excessively large current $I0 > I0S$ is drawn, the output characteristic of the switch-mode power supplies 92-98 moves into the third operating range III, which, after another increase in the output current $I0$ results in the switch-mode power supplies 92-98 being short-circuited and not delivering any more voltage. The system illustrated in figure 6 can then be supplied for a limited period by the batteries 114 before it cuts out completely unless the failure or malfunction is remedied.

The characteristics revealed in the above description, the claims and the figures can be important for the realization of the invention in its various embodiments both individually and in any combination whatsoever.

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Identification Reference List

| | |
|---|---|
| 10, 11, 12 | Switch-mode power supplies |
| 13 | Consuming unit |
| 20 | Switch-mode power supply |
| 22 | Switch |
| 24 | Storage capacitor |
| 26 | Output transformer |
| 28 | Output/free-wheeling diode |
| 30 | LC circuit |
| 32 | Load resistor |
| 34, 35, 36, 37 | Rectifier diodes |
| 38 | Storage and smoothing inductor |
| 40 | Switch |
| 42 | Output/free-wheeling diode |
| 44 | Storage capacitor |
| 50 | First stage |
| 51, 52, 53 | Resistors |
| 54 | Operational amplifier |
| 56 | Blocking diode |
| 58 | Current reduction device |
| 60 | Second stage |
| 61 | Switch |
| 62 | Transformer |
| 63 | Zener diode |
| 64 | Capacitor |
| 65 | Resistor |
| 68 | Controlled switch |
| 70 | Third stage |
| 71 | Input diode |
| 72 | Capacitor |

| | |
|---|---|
| 73 | Resistor |
| 74 | Amplification circuit |
| 75 | Output diode |
| 80 | Pulse width modulation circuit |
| 90 | Mains supply |
| 92, 94, 96, 98 | Switch-mode power supplies |
| 100 – 112 | Consuming unit |
| 114 | Battery |